and July which might apply to the object seen by De Vico, assuming it to have been an intra-Mercurial planet. Leverrier did not attempt to discuss these observations, confining his attention to those made about the equinoxes, clearly belonging to a different body.

GEOGRAPHICAL NOTES

SOME of our contemporaries have been a little premature in appointing the Earl of Northbrook to the presidency of the Royal Geographical Society, for at the time when the announcement was first made his lordship was not even a fellow of the Society. The fact, we believe, is that Lord Northbrook has expressed his willingness to accept his nomination by the Council, but there is no likelihood of any election taking place till the anniversary meeting on May 26th.

AT the meeting of the Geographical Society on Monday evening Dr. James Stewart, of the Livingstonia Mission, East Africa, read a paper on the "Second Circumnavigation of Lake Nyassa." The voyage was undertaken in the little steamer *Ilala* in the latter part of 1877. It was found that Lake Nyassa has hitherto been laid down on our maps too far to the east, and that its position ought to be shifted at the north end as much as thirty miles to the westward. Dr. James Stewart was also fortunate in discovering two harbours such as were needed for the safe navigation of the lake; the one Rombashi inlet or river on the northern coast, and the other the Kambwe lagoon a little to the south of it on the west coast. Mr. James Stevenson afterwards gave a few particulars respecting the explorations now being carried on by Dr. Laws and Mr. James Stewart, of the Bengal Civil Service, in the country on the western side of Lake Nyassa.

THE Abbé Debaize, the leader of the French expedition to Central Africa, sends to M. Richard Cortambert a letter, rejoicing at the success of his expedition so far. He writes from Taboro, in Unyamwezi, and states that hitherto he has been completely successful; there have been no desertions, little expenditure, and no misfortunes of any kind. This good fortune he ascribes to his own excellent health, to his firm discipline, and his personal superintendence of all arrangements. He has a very poor opinion of Miramboa, and thinks the English are striving hard to become masters in Central Africa; indeed he hints that "annexation" is not far off. At Mpwapwa, where the sole white population are an English "reverend, a mason, and a carpenter," there are already four stone houses, while there are English stations in Ukerewe, Uganda, and at Ujiji.

THE *Daily News* Lisbon correspondent states that the Portuguese Minister of Marine has informed the Cortes that he has received a telegram stating that the Portuguese African explorer Pinto, who was separated from his companions at Bihe, has succeeded in traversing Africa from west to east, having reached the Transvaal.

FRANCE and the United States will soon establish a comparison of the longitude of Paris and Washington by cable. As is known, these operations lead to a determination of the velocity of propagation of electric waves. Commander Perrier and M. Lœwy have recently published a volume giving the details of the comparison between Paris, Marseilles, and Algiers.

MR. STANFORD has just published a very fine stereographical map of Zululand, with portions of the adjoining territories. On the bases of what observations there are as to the physical conformation of the country, together with the pretty fair notions we have of the courses of the rivers, a good general notion is conveyed of the character of the surface and its various levels. The map conveys, moreover, a great amount of information in a clear and striking manner, that will be extremely useful to those who wish to understand the history and bearings of the Zulu difficulty.

UNDER the title of "Le Maroc" the current number of the *Tour du Monde* contains the commencement of a translation of M. Edmondo de Amicis' account of his experiences in Morocco in 1875. The present instalment deals with Tangier, and is accompanied by several illustrations.

WE understand that Prof. Geikie, of Edinburgh, will probably deliver a lecture on Geographical Evolution before the Royal Geographical Society on Monday, March 24.

THE Emperor of Austria has presented Captain von Oestreicher with the medal for letters and arts (*literis et artibus*) in recognition of his recent highly interesting geographical work, "Aus fernem Osten und Westen."

DURING last year the following journeys were made by Russian explorers in Central Asia:—Generals Stolyetoff and Razgonoff were accompanied during their mission to Kaboul by several topographers and explorers; M. Oshanin has made explorations in Karategin and Hissar; M. Matséeff in Badakshan and Eastern Afghanistan; M. Grodékoff in Western Afghanistan and Herat; M. Bykoff has explored the Amu darya River from Kobadian to Khiva; M. Yavarsky has traversed for the fourth time the region between Tashkend and Kaboul; M. Mayeff has visited for the second time the hilly track between Karshi, Keliff (on Amu darya), Kobadian, and Hissar; and, finally, the steamer *Samarkand* has navigated the Amu, from Petro-Alexandrovsk to Khodja-Sale.

UNDER the title of Société de Géographie de l'Est, there has been founded at Nancy a new geographical society.

A STUDY IN LOCOMOTION[1]

IF the interest of a scientific expositor ought to be measured by the importance of the subject, I shall be applauded for my choice. In fact, there are few questions which touch more closely the very existence of man than that of animated motors—those docile helps whose power or speed he uses at his pleasure, which enjoy to some extent his intimacy, and accompany him in his labours and his pleasures. The species of animal whose co-operation we borrow are numerous, and vary according to latitude and climate. But whether we employ the horse, the ass, the camel, or the reindeer, the same problem is always presented: to get from the animal as much work as possible, sparing him, as far as we can, fatigue and suffering. This identity of standpoint will much simplify my task, as it will enable me to confine the study of animated motors to a single species; I have chosen the horse as the most interesting type. Even with this restriction the subject is still very vast, as all know who are occupied with the different questions connected therewith. In studying the *force of traction* of the horse, and the best methods of utilising it, we encounter all the problems connected with teams and the construction of vehicles. But on a subject which has engaged the attention of humanity for thousands of years, it seems difficult to find anything new to say.

If in the employment of the horse we consider *its speed* and the means of increasing it, the subject does not appear less exhausted. Since the chariot races, of which Greek and Roman antiquity were passionately fond, to our modern horse-races, men have never ceased to pursue with a lively interest the problem of rapid locomotion. What tests and comparisons have not been made to discover what race has most speed, what other most bottom,

[1] "Moteurs animés; Expériences de Physiologie graphique." [Lecture by Prof. Marey at the Paris meeting of the French Association, August 29 1878.

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what crossings, what training give reason to expect still more speed?

Lastly, as to what is called the exterior of the horse, and his varied paces, specialists have for long devoted themselves to this department. The horseman is trained to distinguish between these different paces, to correct by the education of the horse those which seem to him defective, to fix by habit those which give to his mount more pleasant reactions or a much greater stability. The artist, in attempting to represent the horse, seeks to transfer his attitudes more and more faithfully, to express better and better the force, the suppleness, and the grace of his motions.

These questions, so complicated, I wish to bring before you by a new method, and I hope to show you that the *graphic method* makes light of difficulties which seem insurmountable, discerns what escapes the most attentive observation; finally, it expresses clearly to the eyes, and engraves upon the memory the most complicated notions. The graphic method was almost unknown twenty-five years ago; to-day it is wide-spread. Thus, in almost all countries, recourse is had to the employment of graphic curves as the best mode of expression to represent clearly the movement of administrative, industrial and commercial statistics. In all observatories apparatus known as *registering* or *recording*, trace on paper the curves of variation of the thermometer, the barometer, rain, wind, and even atmospheric electricity. Physiology utilises still more largely recording apparatus; but I shall only require to show you a very small number of these instruments, those which serve to record forces, rates of speed, or to note the rhythms and the relations of succession of very complicated movements.

1. *Of the Force of Traction of the Horse, and the best Means of Utilising it.*—When a carriage is badly constructed and badly yoked the traveller is jolted, the road is injured, the horse is fatigued more than is necessary, and is often wounded by parts of the harness. Science and industry have long sought to discover these inconveniences, to find out their causes in order to get rid of them. But it is only in our own time that great progress has been made in this respect. When we complain of being jolted in a humble cab, we ought to go back in thought to the time when people knew nothing of the hanging of carriages. No roughness of the road then escaped the traveller. A Roman emperor mounted on his triumphant chariot was, in the midst of his glory, as ill at ease as the peasant in his cart. Except some improvements, such as the use of softer cushions, things went on thus till the invention of steel springs such as are now employed, for the leather braces of old-fashioned carriages still left much to desire.

Does this mean that the present mode of suspending carriages by four and even eight springs is the final step of progress? Certainly not. Our present springs diminish the force of jolts, transform a sudden shock into a long vibration; but the perfect spring ought always to maintain a constant elastic force, to allow wheels and axles all the vibrations which the ground demands of them, without allowing any of these shocks to reach the carriage itself. The search for this ideal spring has engaged the attention of one of our most eminent engineers. M. Marcel Deprez has found happy solutions to the problem of perfect suspension; he will, doubtless soon apply these in practice.

A good suspension also saves the carriage by suppressing the shocks which put it out of order and destroy it in a short time. Finally, suspension saves the wheel itself. On this subject let me recall a remarkable experiment of General Morin. On a high road, in good condition, he drove a diligence with four horses at the trot, and laden with ballast instead of passengers. The springs of the vehicle were raised so that the body rested on the axles. After the diligence had passed and repassed a certain number of times, it was found that the road on which it was running was notably deteriorated. The springs of the carriage were replaced and the same movements were repeated on another part of the road; the marked deterioration was no longer produced. It is thus clearly proved that a good suspension is favourable to a good condition of the roads.

But with non-suspended vehicles, in order thus to shock the passengers, disjoint the carriage, and abuse the road, force is necessary. It is the horse which must supply this; so that, independently of the useful work which we demand of them, the animal supplies still other work which gives rise to a multitude of shocks, and has only injurious effects. The employment of suspending springs has rendered the double service of suppressing injurious vibrations and of collecting into a useful form all the work which they represent.

Is this all? Do there not remain, even with the best carriages, other vibrations and other shocks which must be pursued and destroyed in order to render more perfect the conditions of traction? You have all experienced, at the moment of the sudden start of a carriage, and even at each stroke of the whip on a living horse, horizontal shocks which sometimes throw you to the bottom of the carriage. In a less degree, shocks of the same kind are produced at each instant of traction, for the speed of the horse is far from being uniform, and the traces are subjected to alternate tension and slackness. Here are veritable shocks which use up part of the work of the horse in giving only hurtful effects which bruise and contuse the breast of the animal, injuring his muscles, and, in spite of the padding of the collar, sometimes wounding him. To prove the disadvantages of this kind of shocks, some experiments are necessary. I have borrowed one from Poncelet; it is easily made, and any one may repeat it. I attach a weight of 5 kilos to the extremity of a small string; taking hold of the free extremity of this, if I gently raise the weight, you see that the cord resists the weight of 5 kilos and holds it suspended. But if I attempt to raise the same weight more rapidly, I bruise my fingers, the cord breaks, and the weight has not budged. The effort which I have made has been greater than the preceding, since it has exceeded the resistance of the cord; but the duration of this effort has been too short, and the inertia of the weight not being overcome, all my exertion has been expended in injurious work. If, instead of an inextensible cord, I had attached to the weight a cord a little extensible, the sudden effort of elevation which I made would have been transformed into an action more prolonged, and the weight would have been raised without breaking the cord and bruising my fingers. To render the phenomenon more easy of comprehension, I shall make a new experiment under conditions a little different.

You see on a vertical support (Fig. 1) a sort of balance-beam, which bears on one of its arms a weight of 100 grammes, on the other a weight of 10 grammes suspended at the end of a cord one metre long. Between these two unequal weights the beam is maintained by a spring-catch, which prevents it from falling to the side of the heavier weight, but which, on the other hand, permits the beam to incline in the opposite direction, if we bring to bear on the end of the cord an effort greater than the weight of 100 grammes. But, by letting the smaller weight fall from a sufficient height, at the moment when this reaches the end of its course, it will stretch the cord which holds it, and will develop what is called a *vis viva*, capable of raising the weight of 100 grammes to a certain height; but this elevation will only take place on condition that the application of this force does not give rise to a shock. If the cord which sustains the weight of 100 grammes is inextensible, and if that which bears the weight of 10 grammes is the same, at the moment of the fall of the latter, you will hear a snap; a shock agitates

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the whole apparatus, but the weight of 100 grammes is not raised.

Now suspend this weight of 100 grammes to an india-rubber cord or an elastic spring, and repeat the experiment. You see each time that the weight falls that the 100-gramme weight is raised to a certain extent. But this elevation is effected under peculiar conditions. At the moment when the weight falls and the cord is stretched, the balance inclines, stretching the elastic spring, but the mass of 100 grammes does not yet move; it is only when this spring is stretched that the mass, obedient to the prolonged action of this elastic spring,

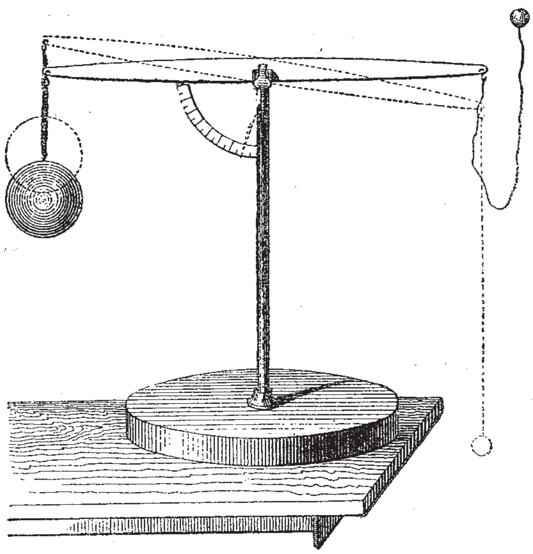

FIG. 1.—Apparatus to show that a *vis viva* directly applied to the displacement of a mass is lost in a shock, while the same force transmitted by an elastic medium may perform work.

begins to move and rises, representing a certain amount of work accomplished.

Thus, the suppression of shock in traction, economises a certain part of the moving labour; it is *then* advantageous to give to the traces of a carriage a certain elasticity. One of the most simple methods consists in interposing between the trace and the carriage an elastic medium. Here are some of these elastic pieces, which I call *tractors*. One of the patterns has been made by M. Tatin; it is composed of a spring which is compressed by traction and deadens the shock. The other is formed of a similar spring placed in the very inside of the carriage-trace.

If you wish to be convinced of the advantage of this mode of traction, yoke yourself to a hand-barrow by

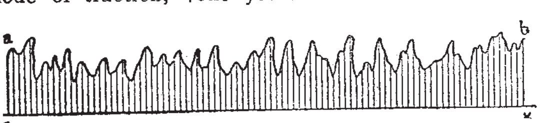

FIG. 2.—Tracing of the dynamograph for a vehicle drawn by a horse.

means of a rigid leather strap, such as you see used in the streets of Paris or London, where too often man is employed to drag burdens. When you have well noted the painful shocks which this mode of traction transmits to the shoulders, place between the strap and the barrow the elastic tractor and repeat the experiment. After that no doubt is possible; the shoulders are no longer bruised by the shaking of the pavement, and a comfort is experienced which will evidently be experienced in the same degree by a horse placed in conditions of elastic traction.

To obviate suffering to men and animals is unfortunately not a motive sufficient to induce everybody to modify the old system of harnessing. To certain minds known as *positive*, it is necessary to prove that elastic traction has economical advantages, and that a horse thus harnessed is able to draw heavier loads. This fact, which results from the experiments which you have seen, requires, to be rigorously proved, the aid of the graphic method. It is to the genius of Poncelet that we owe the record of work expended by different motors.

Everybody knows what a dynamometer is, viz., a spring which, yielding to tractions exerted upon it, is deformed in proportion to the efforts developed. Let us adapt to a spring of this kind a pencil which touches a strip of paper, and let us so arrange things that the movements of the wheel of a carriage shall impress upon the paper a motion of translation. While the effort of traction of the horse will communicate to the spring movements more or less extended, the progress of the carriage will

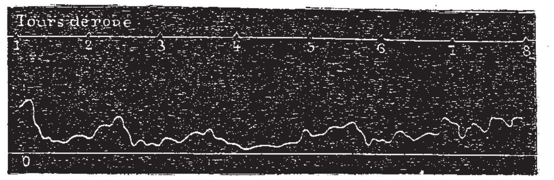

FIG. 3.—Tracing of the dynamograph for a vehicle drawn with an elastic intermediary.

draw out the paper, and from these combined movements will result a curve (Fig. 2), which can be resolved into a series of ordinates or vertical lines in juxtaposition, expressing by their unequal heights the series of efforts resulting from each element of the road traversed. The sum of these elementary efforts, otherwise the surface of paper limited in height by the flexures of the curve, will be the measure of the work expended. If we record in a comparative manner the work done by the same vehicle harnessed with rigid traces or supplied with elastic tractors, we see (Figs. 3 and 4) that the *area* of the curve is greater, that is, that there has been more work expended, while rigid traces have been used. In the most favourable cases that I have met with, the economy of work by elastic traction has been 26 per cent.

But, it may be objected, the recording dynamometer itself constitutes an elastic intermediary which suppresses

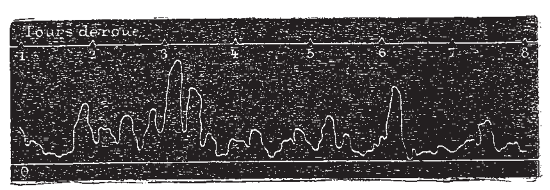

FIG. 4.—Tracing of the dynamograph for a hand-barrow drawn by a rigid trace.

the shocks. But it is not the ordinary dynamometer which I have used in my experiments, but a special dynamometer which undergoes under the strongest tractions only an almost insignificant elongation. This elongation, amplified by certain organs and transmitted to a distance by a lever fitted with a pen, is recorded in the form of a wavy curve in conditions referred to above. To sum up, in the employment of animated motors for the drawing of burdens, to find out wherever they produce shocks and vibrations, and to absorb them in elastic springs which restores to useful work a force that seemed only to destroy vehicles, tear up the roads, cause the animals to suffer—such is the direction in which much progress has been realised, and much more may still be realised.

2. *Of the Speed of Animated Motors.*—I shall per-

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haps astonish many of you by saying that the speed of a vehicle is one of the things most imperfectly known. It is generally believed to be sufficiently expressed by stating how much way has been made and how much time has been occupied for that. I have come, you may say, from the Pont de Sèvres to the Madeleine in $41\frac{1}{4}$ minutes; the road is well mile-stoned, I possess a good watch; what greater precision do you require? Assuredly you have measured accurately the space traversed and the time employed, but that constitutes only the expression of a mean speed resulting from a series of variable speeds, of accelerations, of retardations, and sometimes of stoppages

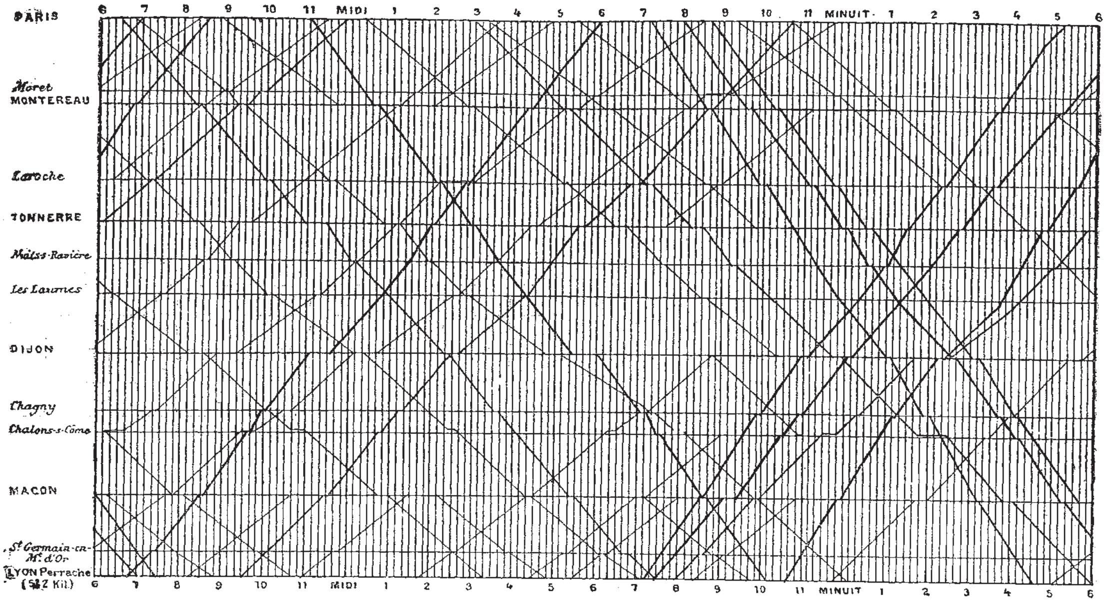

FIG. 5.—Graphic of the progress of trains upon a railway, after Ibry's method.—When we place the figure before us we read from the left, on the axis of the ordinates, the series of stations, that is, the divisions to be run over; the distance between the stations on the paper is proportional to the kilometric distances which separate them. In the horizontal direction, that is, on the axis of the abscissæ, are counted the divisions of time in hours, themselves subdivided into spaces of ten minutes each. The breadth of the table is such that the twenty-four hours of the day are represented on it, commencing at 6 A.M., and ending next day at the same hour. If we wish to express that a train is on a certain point of the line at a certain hour, we shall point out its position on the table, opposite the station or any point of the line which it occupies and on the properly chosen division of time. A single point of the table satisfies these conditions. At successive instants the train will occupy points on the table always different; the series of these points will give rise to a line which will be descending and oblique from left to right for trains coming from Paris, while it will be ascending and oblique in the same direction for trains going to Paris. The line which corresponds to each of the trains expresses the hours of departure and arrival, the relative and absolute rates of the trains, the instant of passing each of the stations, and the duration of stoppages. In fact, if we consider any particular train, we see that a train starts from the station at Paris at 11 A.M.; if we follow this train in its progress, we find that it has seven stoppages (during which it is not displaced in space, but only in time). These stoppages are translated by the horizontal direction of the line, opposite the station where they take place; the length of this horizontal line measures the duration of the stoppages. The line of the train, followed to the end, shows that the arrival takes place at 6 P.M.; but, if we reckon the distance on the axis of the ordinates, we see that 512 kilometres have been traversed in eleven hours ten minutes, stoppages included, which gives a mean rate of about 46 kilometres per hour.

where time is quite unknown. A rigorous measurement of rates supposes the road traversed by the vehicle at each instant; in other words, the position which it occupies upon the road. It is thus that physicists have determined the accelerated motion of the fall of bodies—Galileo and Atwood, by means of successive measurements, Poncelet and Morin by means of that admirable apparatus which traces by a single stroke the curve of a movement.

This machine is now too well known to need description; however, I shall make it work before you in order to interpret its language and to show how a graphic curve translates all the phases of a movement. The parabolic curve traced expresses for each of its points the position in which the body is found at each of the instants of its fall; it thus supplies the most complete information on the nature of the movement. But if, knowing only the space run over and the time employed, we join the two extreme points of departure and arrival by a straight line, that line, which will express the mean rate of the fall, will not correspond to any of the rates which the body has successively possessed.

The expression of movement by a curve has been put into practice. An engineer named Ibry has devised a method of representing graphically the progress of trains upon a railway. This mode of representation, incomparably more explicit than the tables of figures of our railway *indicators*, has not yet got into the hands of the public; and this is to be regretted, for it gives a genuine interest to a journey, as you may see by inspection of one of these graphics.

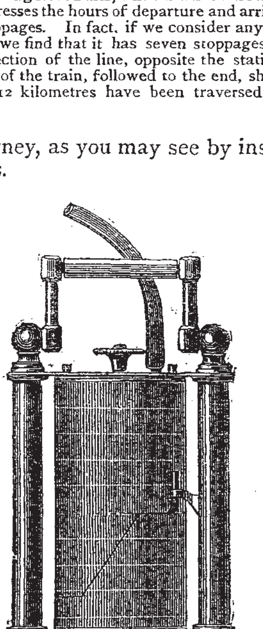

FIG. 6.—Odograph, reduced to one-third of its diameter.

The table which you see (Fig. 5) is prepared by engineers according to the regulation progress of trains

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a progress supposed uniform; we see, in fact, that the lines of progress are all straight, joining to each other the two points which express the place and time of departure, the place and time of arrival. It does not then take into account the real movement of the train, which is accelerated or retarded under a great number of influences. The problem which we seek to solve, that of a graphic expression of the real rate of a vehicle, supposes that the carriage itself traces the curve of the roads traversed, in function of time. By means of the apparatus which I present to you, and which I call *Odograph* (Fig. 6), a waggon or any kind of carriage traces the curve of its movement with all its variations.

This apparatus, based on the same principle as the Poncelet and Morin machine, is composed of a tracing style which moves parallel to the generatrix of a revolving cylinder covered with paper. The movement of the style follows all the phases of that of the carriage, but on a very reduced scale, in order that the tracing of a distance of several myriametres may be contained in the dimensions of a sheet of paper. As to the movement of the cylinder, it is uniform, and commanded by clockwork placed in the interior. In order that the movement of the style may be proportional to that of the vehicle, things have been so arranged that each turn of the wheel causes the style to advance by a small quantity, always the same. But as a turn of the wheel always corresponds to the same distance accomplished, the faster the vehicle travels the more turns will the wheel make in a given time, and the more movements of progression will the style undergo. This solidarity between the movements of the wheel and those of the style is obtained by means of a small excentric placed on the vane. At each turn there is produced a puff of air, which, by a transmitting tube, causes a tooth of a wheel of the apparatus to escape, and the style to advance by a small quantity.

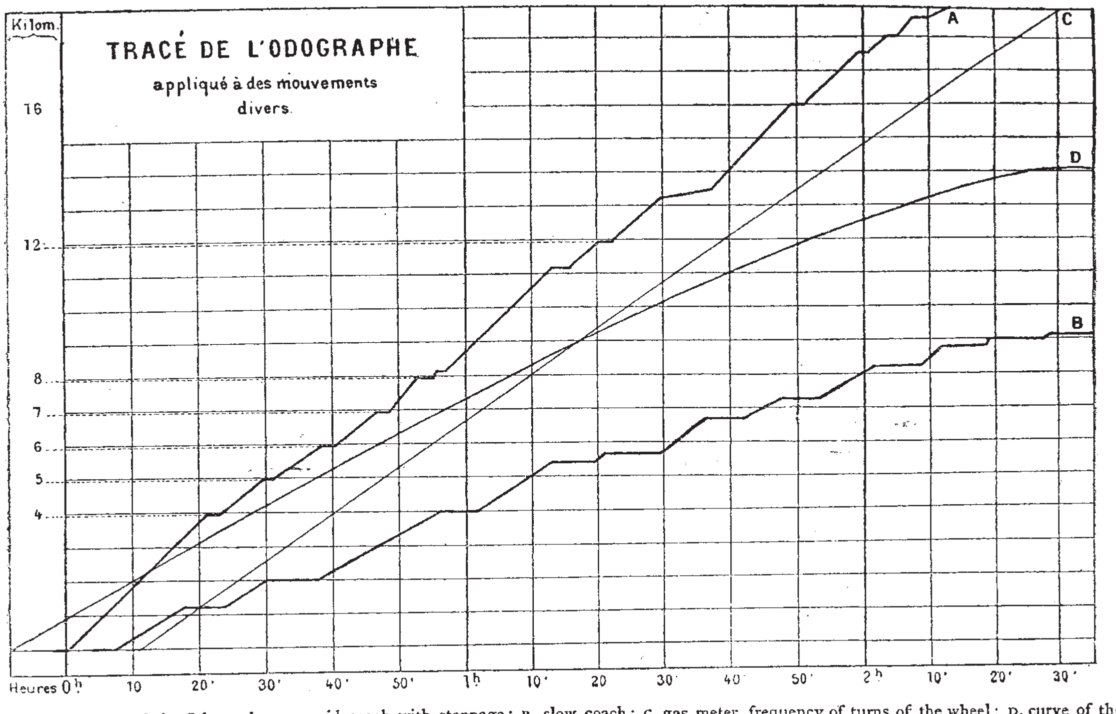

FIG. 7.—Tracings of the Odograph. A, rapid coach with stoppage; B, slow coach; C, gas meter, frequency of turns of the wheel; D, curve of the turns of a clock wheel-work with fly.

Similar effects may be obtained by means of electro-magnetic apparatus. Thus the swifter the vehicle goes the more rapidly will the line traced ascend; the comparative slope of various elements of the tracing will express the variations of rate, as seen in Fig. 7.

If we wish to learn the absolute value of time and distance, it is sufficient to know that each minute corresponds to a millimetre counted horizontally on the paper, and that each kilometre corresponds to a certain number of millimetres traversed by the style in the vertical direction. The course of the style, which corresponds to a kilometre, ought to be experimentally determined for each vehicle, for the perimeter of wheels is not always the same. But it is clear that, if from each kilometre-stone to another we obtain five millimetres, for example, for the course of the style, this length will always be found to be traversed each kilometre by the same vehicle. Our apparatus is then a measurer of distances, and dispenses with the necessity of attending to the existence of kilometre-stones; it enables the distance traversed on any road whatever to be estimated, and even when there is no beaten track. Thus in a journey of discovery we may measure the distance traversed by a cart. To remain in the conditions of ordinary life, have we not sometimes, in the country, a choice of two or three roads to go from one place to another? To know which is the shortest, we appeal to the watch, as if the least duration of a walk corresponded to the least distance. The odograph will give in this respect very precise information.

There is again a great number of questions which we ask daily without being able to solve them. Does such a draught horse go quicker than such another? Does this trot better to-day than yesterday? By increasing the ration of oats do we increase speed? Compare the slope of two curves of rates, and you will have the reply to all these questions without being obliged to make special experiments on a measured road, watch in hand.

It is not only to the speed of vehicles that the registering apparatus applies; it traces, though with less precision, the rate of progress of men and animals. We

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slip into our boots a bellows sole, which is connected by a tube with a portable odograph. Each pace impresses on the style a small movement, as does each turn of the wheel of a carriage; and if the paces be absolutely equal, we may measure with certainty the distances travelled. In walking on level ground we take steps of astonishing regularity; but if the ground rises, the step gains in length; in descents, on the contrary, the steps are shortened. There may result from this slight errors in the distances traversed. Notwithstanding this, the employment of this apparatus will effect a great progress; it may be substituted with many advantages for the pedometer, which gives, at the end of a certain time, only the paces accomplished, without taking count of the stoppages or the changes of rate.

In short, when we make an experiment on a measured road, if there are produced variations in the length of the tracing represented by a kilometre, we conclude therefrom variations in the length of the pace. Such variations are observed under the influence of the slope of the country, the nature of the soil, the boots we wear, the rate of walking, or the weight carried. These studies in applied physiology have, I believe, a great practical importance, and numerous applications to the march of troops in a campaign.

(*To be continued.*)

WILLIAM KINGDON CLIFFORD

IT was with feelings of the deepest regret that we last week recorded the sad loss the scientific world and the country at large had sustained by the death, at the early age of thirty-three, of one of the deepest thinkers and most brilliant writers this century has seen. W. K. Clifford was the eldest son of the late Mr. William Clifford, J.P., of Exeter, and was born on May 4, 1845. Receiving his earlier education at the school of Mr. Templeton of that city, he proceeded to King's College, London. Here he at once gave evidence of his great powers by obtaining in his first year, 1861, the Junior Mathematical and Junior Classical Scholarships, as well as the Divinity prize. In the two succeeding years he gained the Classical and Mathematical Scholarships of the year, and in addition to the Inglis Scholarship for English language an extra prize for the English essay. Even at this time, whilst pursuing with such success so many branches of study, he sought a more genial occupation for his active mind in constantly reading in the college library the higher mathematical works to which he could obtain access, and towards the end of his school life, as also during his time as an undergraduate at Cambridge, he took great delight in solving and propounding problems in the *Educational Times*. While still in his eighteenth year the "Analogues of Pascal's Theorem" was written, and constitutes the first of his papers recorded in the Royal Society Catalogue. Passing from his school life, we find him entered at Trinity College, Cambridge, securing a Foundation Scholarship, college prizes in each academic year, and the English Declamation prize. Early in his career at the University he read such portions of the Tripos subjects as possessed any interest for him, and soon turned his attention to the study of the original writings of Sylvester, Cayley, Salmon, and some of the great Continental masters. In vain did his private tutor, the Rev. Percival Frost, who always had the highest admiration for him, and was anxious that he should attain his proper place in the Mathematical Tripos, urge him to devote a little more attention to examination subjects; his mind could tolerate no such restraint; nothing but the fresh and original thoughts of the greatest mathematical writers could satisfy his wants.

His neglect of the examination subjects was such that it is said he only once wrote out a paper of bookwork questions, and that under the impression that he was solving problems; many also, well qualified to judge, were agreeably surprised when he obtained the position of second Wrangler in the Mathematical Tripos of 1867, while his success in obtaining the second Smith's prize was doubtless anticipated from the wider scope for his talents afforded by that examination. During this period the course of his future work is clearly seen; divinity and classics, at one time so ardently studied, are laid aside, and the writings of the great philosophers divide his attention with the study of higher geometry. One of his longest and most fully worked out papers, "Analytical Metrics," published subsequently in the *Quarterly Journal of Mathematics*, was written at this time, 1864.

Of the circle of intimate friends Clifford formed at this time, nothing need here be said; two or three have gone before him, the remainder have watched with the deepest interest and pleasure his widening reputation and growing influence, and are now left with a blank no one can fill, and all bear in affectionate remembrance his ready sympathy, delicate sense of humour, and sweetness of disposition. His success in the Trinity Declamation prize, and his popularity in the debates at the Cambridge Union Society, showed him to be a speaker of no common order, but it was not until he delivered his first Friday evening lecture at the Royal Institution of London, the year after he took his degree, and subsequently at the Sunday Lecture Society, that crowded audiences bore testimony to his extraordinary power of lucid exposition. The Royal Institution lecture, "On some of the Conditions of Mental Development," delivered March 6, 1867, was the first time he addressed a large public audience, which included many of the leading thinkers of the time, and from that day he took a recognised position amongst them. A short extract from this lecture reflects the habit of his mind on leaving the University, and indicates plainly that the course of study pursued while an undergraduate, probably by many thought misguided, was, in reality, the expression of a deep inward conviction. Speaking of the mind, he says, "still less must it tremble before the conventionalism of one age, when its mission may be to form the whole life of the age succeeding. No amount of erudition, or technical skill, or critical power, can absolve the mind from the necessity of creating, if it would grow. . . . . The first condition of mental development, then, is that the attitude of the mind should be creative, rather than acquisitive;" and again, "It is quite possible for conventional rules of action, and conventional habits of thought to get such power that progress is impossible." Two other Friday evening lectures were given later by Clifford, on "Theories of the Physical Forces," Feb. 18, 1870; and on "Babbage's Calculating Machines," May 24, 1872; in the latter case no pains were spared by him to thoroughly master all the mechanical details of those intricate machines, and for years afterwards he would occasionally discuss schemes for the completion of the analytical engine. In public lecturing his greatest success was probably the evening lecture at the meeting of the British Association at Brighton, August, 1872, "On the Aims and Instruments of Scientific Thought." Throughout this lecture the key-note of so much of Clifford's most powerful writing can readily be detected, as may be shown by a short extract:—"If you will allow me to define a reasonable question as one which is asked in terms of ideas justified by previous experience, without itself contradicting that experience, then we may say as the result of our investigation, that to every reasonable question there is an intelligible answer, which either we or posterity may know. . . . By scientific thought we mean the application of past experience to new circumstances, by means of an observed order of events. . . . Remember then that it (scientific thought) is the guide of action; that the truth which it arrives at is not that which

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